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# EVIDENCE FOR VALENCE NEUTRON CAPTURE IN S-WAVE NEUTRON CAPTURE IN $^{36}$Ar and $^{54}$Fe*

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The valence and channel neutron model of Lane and Lynn remarkably account for partial radiative widths of neutron resonances in the 3p-giant resonance. In this investigation, evidence is presented for valence neutron capture at and in the neighborhood of the 3s- giant resonance in target nuclei Ar-36 and Fe-54. In addition, the variation of the correlation coefficient $\rho(\Gamma_{\gamma ij}\, E_\gamma^{-n},\, (2J+1)\, S_{dp})$ with the reduction power factor n of the γ ray energy is studied.

(Thermal capture spectra; valence capture in $^{36}$Ar and $^{54}$Fe)

## Introduction

A considerable number of recent investigations have been devoted to the study of nonstatistical effects in the neutron capture mechanism in the thermal and resonance region. These nonstatistical effects generally manifest themselves in the observation of enhanced gamma ray transitions to low lying states with large single particle character. The interpretation[1,2,3] of the thermal capture data in terms of either of the simple reaction mechanisms described below is one of the interesting aspects of these investigations. Three proposed simple reaction mechanisms[4,5] which quantitatively explain these observations are (1) hard sphere capture, (2) channel capture, and (3) valence capture. Other reaction mechanisms such as doorway state formation will not be treated here. The hard sphere or potential capture cross section for an s-wave neutron undergoing a transition to a final p state is expressed by:

$$\sigma_\gamma(\text{hard sphere}) = \frac{0.062}{R(E_n)^{\frac{1}{2}}} \left(\frac{Z}{A}\right)^2 \theta_f^2 \frac{(2Jf+1)}{6(2I+1)} \left(\frac{y+3}{y+1}\right)^2 y^2 \quad (1)$$

In this relation, $\theta_f$ is a reduced dimensionless neutron width of the final state and $y = k_{NL} R$ where $k_{NL}$ is the wave number corresponding to the binding energy of the final state. The interesting features of this relation is that the hard sphere partial capture cross section is (i) correlated with the (d,p) spectroscopic factors of the final states and (ii) it follows an $E_\gamma$ energy dependence. Estimates of (1) in the mass region around A = 50 are about 0.3b.

The channel capture contribution[4] to the radiative width $\Gamma_{\gamma if}$ of an s-wave resonance with spin J is given by:

$$\Gamma_{\gamma if} = \Gamma^o_{in}\, \theta_f^2 \left(\frac{Z}{A}\right)^2 \frac{y^4}{R^3} \left(\frac{y+2}{y+1}\right)^2 (2Jf+1) \begin{Bmatrix}110\\ JJf\end{Bmatrix}^2 \text{in eV} \quad (2)$$

where the last term is the Wigner 6-j symbol. Note that the energy dependence of $\Gamma_{\gamma if}$ is closely proportional to $E_\gamma{}^2$.

The valence capture[6] component for an E1 transition is expressed by:

$$\Gamma_{\gamma if}(E1) = \frac{16\pi k^3}{9}\, \theta_i^2\ \ \theta_f^2 \left(\frac{eZ}{A}\, I_{if}\, M_{if}\right)^2 \quad (3)$$

$M_{if}$ and $I_{if}$ are the angular momentum vector coupling coefficients and the radial overlap integrals for E1 transitions respectively. It is interesting to note that the limits of integration of $I_{if}$ are from 0 to ∞. For the case of channel capture, the integration was carried out in the external region to arrive at relation (2). In this investigation, the γ ray energy dependence of the radial overlap integrals in (3) was studied for s-wave capture in the mass region 50, using Saxon-Wood potential. The results show that the energy dependence of $I_{if}$ is not very strong; specifically $I^2_{if} \propto E_\gamma^{-\frac{1}{4.4}}$.

## Neutron Capture Mechanism in Ar-36

The γ ray intensities due to thermal neutron capture were measured by Von Wille[6] using a highly enriched sample of Ar-36 (99.9%). Hardell and Beer[7] using a natural argon sample observed several Ar-36 lines and reported their intensities relative to Ar-40. The Ar-36 γ ray intensities were converted here to absolute values with the aid of the thermal capture cross sections of Ar-36 and A4-40 ($\sigma_\gamma$ = 0.66b) and their natural abundances as reported in BNL-325 (1973). As shown in Table I, very good agreement is obtained between the two sets of measurements.

A display of the energy level diagram of Ar-37 and γ ray intensities due to thermal neutron capture is shown in Fig. 1. The (d,p) spectroscopic factor $S_{dp}$ as indicated in the figure are weighted averages of the most recent data. One notes immediately that the strongest E1 transitions are populating final states with large spectroscopic factors. Analysis of the data show that the γ ray intensities are highly correlated with the (d,p) data, $(2J-1)S_{dp}$. When such significant correlation is established, one seeks to find out whether the reaction mechanism is dominated by hard sphere, channel, or valence capture. The magnitude as well as the γ ray energy dependence of the intensities can shed light on this question. As a result, partial radiative widths are calculated in the framework of the valence neutron model using the parameters of the bound level derived by Mughabghab and Magurno.[8] In these calculations, the normalization procedure described by Lane and Mughabghab[9] is applied. A comparison between predicted and measured partial radiative widths is described in Fig. 2 which shows good agreement between the two sets. Finally, it is interesting to point out that detailed analysis of the correlation coefficient:

$$\rho(\Gamma_{\gamma ij} E_\gamma^{-n},\ (2J+1)\ S_{dp})$$

is optimized for $n_{max}$ = 1.2, a result which is not reconciled with channel or valence capture for which $n_{max}$ = 2 or 3 respectively.

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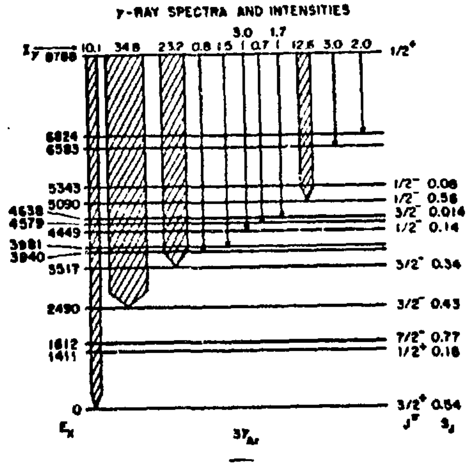


Fig. 1

Energy level diagram and thermal neutron capture γ ray intensities of Ar-37

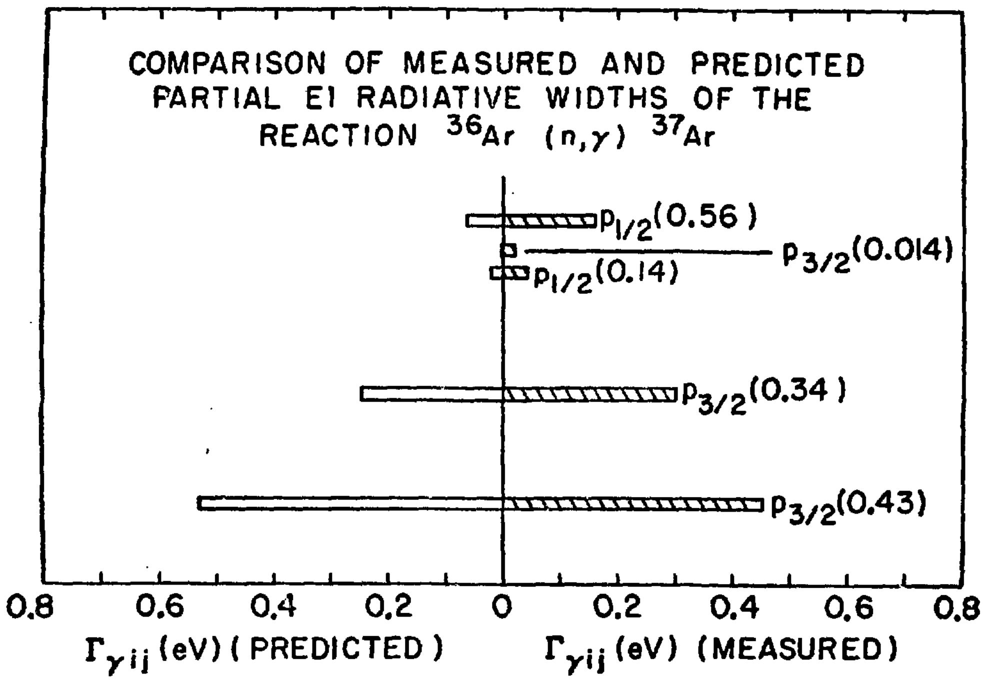


Fig. 2

Comparison of measured and calculated partial radiative widths of $^{36}$Ar $(n,\gamma)$ $^{37}$Ar

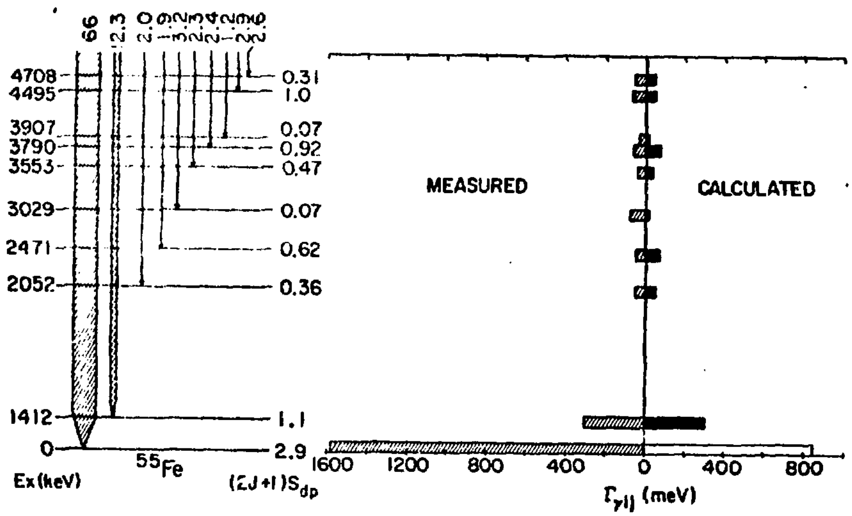


**Fig. 3**

Energy level diagram and comparison of measured and calculated partial radiative widths of $^{54}Fe$ (n,$\gamma$) $^{55}Fe$

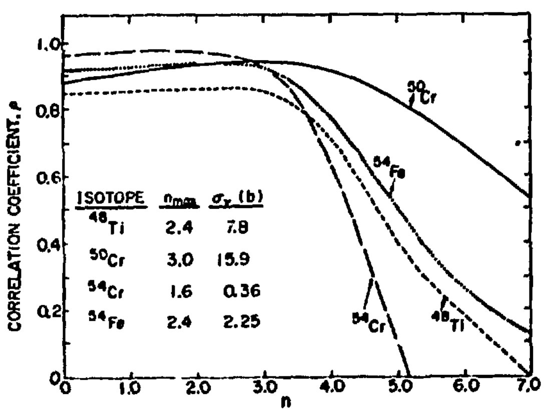


**Fig. 4**

Study of the variation of the correlation coefficient $\rho$ with the reduction factor n

## Neutron Capture Mechanism in Fe-54

Fe-54 is located in the mass region where the 3 s-wave neutron strength function attains a maximum value and where it is expected that the single particle 3s state is located just near the neutron separation energy. In this discussion we report Fe-54 as another candidate for valence capture. Analysis of the thermal cross sections of Fe-54 in terms of positive energy resonances indicates that the thermal capture cross section is accounted for in terms of the 7.8 keV resonance, which information is used to derive a radiative width of 2.4 eV for this resonance. In addition, this indicates that the thermal capture γ ray intensities can be considered as due to capture in the 7.8 keV resonance, neglecting interference effects. The energy level diagram and thermal capture γ ray intensities[10] of Fe-55 are described in Fig. 3. The partial radiative widths due to valence capture process are calculated and compared with the experimental values. As shown, the agreement between measured and calculated values is reasonably good. The calculated ground state radiative width is about half the measured value. This could possibly be due to interference effects. As a result, it will be of interest to carry out γ ray spectra measurements due to capture in the 7.8 keV resonance. Finally, the variation of the correlation coefficient with the reduction power factor, n, is studied. The results illustrated in Fig. 4 show that ρ is maximized for n = 2.4 in agreement with channel or valence capture. For comparison, similar studies carried out on Ti-48, Cr-50, and Cr-54 are shown in the Fig. 4.

## References


1. J. Kopecky, A. M. J. Spits, and A. M. Lane, Phys. Letters 49B, 323 (1974)
2. S. F. Mughabghab, in Second International Symposium on Neutron Capture Gamma Ray Spectroscopy and Related Topics, Petten, the Netherlands Sept. 2-6, (1974)
3. R. E. Chrien in Statistical Properties of Nuclei Ed. J. B. Garg (Plenum Press, New York, 1972) p.233
4. A. M. Lane and J. E. Lynn, Nucl. Phys. 17, 563, 586 (1960)
5. J. E. Lynn, The Theory of Neutron Resonance Reactions, p.333 (Clarendon Press, Oxford, England 1968)
6. Von P. Wille, Atomkerenergie 13, 383 (1968)
7. R. Hardell and C. Beer, Physica Scripta 1, 85 (1970)
8. S. F. Mughabghab and B. A. Magurno, contribution to this conference.
9. A. M. Lane and S. F. Mughabghab, Phys. Rev. C, 10, 412 (1974)
10. J. P. Kopecky, K. Abrahams and F. Stecher-Rasmussen Nucl. Phys. A188, 535 (1972)


Table I
γ Ray Intensities of $^{36}Ar$ $(n,\gamma)$ $^{37}Ar$

| γ Ray Energy (keV) | $E_x$ (keV) | (6) $I_\gamma$ (photons/100 capture) | (7) $I_\gamma$ (photons/100 capture) |
|---|---|---|---|
| 8790.8 | 0 | 10.9±0.8 | 10.1 |
| 6300.2 | 2491 | 37.5±3.0 | 37.1 |
| 5273.5 | 3517 | 25.0±1.5 | 18.2 |
| 4851.8 | 3939 | 0.8±0.1 | |
| 4342.3 | 4449 | 1.6±0.2 | |
| 4211.6 | 4579 | 3.2±0.2 | |
| 4153.0 | 4638 | 0.8±0.1 | |
| 3981.4 | 4810 | 1.8±0.2 | |
| 3700.2 | 5091 | 13.4±0.9 | |
| 2599.6 | 6191 | 3.1±0.5 | |
| 2107.5 | | 23.7±0.1 | 18.6 |
| 1410.6 | | 33.0±0.5 | 31.0 |